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Efficacy of Microbial Inoculant in Conserving Physical Properties of Soil Derived from Coastal Plain Sand in Akwa Ibom State, Nigeria

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ABSTRACT

The need to increase agricultural production to meet the high food demand of the increasing world population has posed a serious concern hence the need to maintain soil fertility and productivity. Overtime, the use of chemical fertilizers has shown a serious health effect on humans, farm animals and the environment. Recently, research have proven the use of alternative technology using Microbial Inoculant to boost food production while minimizing the health hazards they pose to the environment, humans and farm animals. Microbial inoculants are of growing interest for their potential role in improving soil fertility and enhancing an increase in crop yields and their nutrients contents. This experiment was carried out to study the effects of microbial inoculant on soil physical properties at Domita farms, Uyo, Akwa Ibom State. The treatment used was CHC-AGRITECH (Farmers' Friend) Microbial inoculant at 5 levels of application (Control= 0kgFF/ha, FF1= 1kgFF/ha applied once, FF2=1khFF/ha applied 2 times, FF3=1kg/ha applied 3 times, FF4=1kg/ha applied 4 times). The result showed that FF3 treatment had the lowest bulk density value (1.19Mg/m) relative to control which was > 1.23Mg/m in the two periods of study. Similarly, farmers friend increased (p<0.05) saturated hydraulic conductivity (SHC), with FF2 treatment having the highest value (1.89cm/hr), control soil had lowest SHC (0.91cm/hr). Soil of FF4 treatment had the highest (P<0.05) saturated moisture content and field capacity. The FF1 treatment has the highest aggregated silt and clay (ASC) value of >4%, that of control soil was <3.9%. Soil under FF2 treatment has the highest water-stable aggregates. It is recommended that farmers in the study area apply CHC-AGRITECH (Farmer's friend) microbial inoculant to improve soil structure, quality and productivity.

Keywords: *Microbial inoculant, aggregates, bulk density, mean weight diameter, physical properties*

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INTRODUCTION

Microbial inoculant refers to formulations composed of beneficial microorganisms that play an important role in soil ecosystems for sustainable agriculture. Microbial inoculants are environmentally friendly and are a potential alternative to chemical fertilizers and pesticides (Babalola and Glick, 2012). They are composed of active strains of microorganisms which directly or indirectly stimulate microbial activity and hence improve mobility of nutrients from soil (Suhag, 2016). They could be phytostimulants, bio-fertilizers or microbial bio-control agents (Alori *et al*., 2017). They provide protection against a range of different pathogens and they are effective bioherbicides (Babalola, 2010). The waste products produced by soil organisms, which differ in terms of their types and functions, effectively impact soil structure, quality and productivity, and the environment (Costa *et al.*, 2018).

Microbial activity is generally related to organic matter, soil texture, bulk density, moisture content, nutrient content, and reaction (Bilen et al., 2021). Artyszak and Gozdowski (2020) emphasized that soil pore properties effectively spread bacteria.

Furthermore, increased pore content due to the decrease in soil bulk density causes an increase in bacterial cells. Extracellular polymeric substances (such as polysaccharides and polyuronides) secreted by many soil bacteria may affect the formation and stability of soil aggregates (Zhang *et al*., 2021). Due to these events, the development of soil structure may ensure good physical conditions and resistance to soil dispersion and degradation (Costa *et al*., 2018).

Bacillus species also secrete exopolysaccharides and siderophores that inhibit or prevent the movement of toxic ions, maintain an ionic balance, and promote water uptake by roots (Costa *et al.,* 2018). These compounds also inhibit pathogenic microbial populations. Bacillus species are considered safe because they produce beneficial substances for soil properties, plant growth, and industrial compounds (Radhakrishnan *et al.,* 2017). These products have sustainable effects on the development of organo-mineral complexes in the soil, retaining soil water and nutrients, supply water to plants, drought stress resistance, contributing to physical contact between plant roots and soil particles, development of aggregation, and promoting microbial activity and carbon storage (Wang *et al.*, 2015).

The type and abundance of microbial communities are the key indicators for the soil quality index and effectively managing agricultural systems (Kennedy and Smith, 1995). This research aims to evaluate the efficacy of microbial inoculant in conserving soil physical properties derived from coastal plain sand of Akwa Ibom State, Nigeria.

MATERIALS AND METHODS

Site description

This research was carried out at Domita Farms Uyo, Akwa Ibom State. The study area lies between Latitudes 4^0 32' and 7^0 31' North, and Longitudes 7^0 25' and 8^0 25' East. The State is bounded on the North by Abia State; on the East by Cross River State, on the West by Rivers State, and on the South by Atlantic Ocean (Ekpoh, 2015).

Sample collection

Soil samples from each experimental plot were collected using soil auger and bulked for the determination of particle size distribution using Calgon as dispersant which microaggregate stability indices, aggregate size distribution was calculated. Samples were collected using core samplers, covered with coligo cloth and with a rubber band and were all properly labeled for laboratory analysis for the determination of Hydraulic conductivity which bulk density, porosity and moisture content were calculated.

Experimental design

The experimental design used for the study was a Randomized Complete Block Design (RCBD) with five treatments. The microbial inoculant used was CHC-AGRICTECH Farmers friend. The rate of microbial inoculant (MI) used was 1kg per hectare. This was dissolved in 200 litres of water. This translates to 1.35g per plot (dissolved in 30 litres of water) and applied at 5 levels in split application as follows: No application of MI (FF0), the rate was applied once (FF1), the rate was divided into two and applied two times (FF2), the rate was divided into three and applied three times (FF3), the rate was divided into four and applied four times (FF4). These levels constituted the experimental treatments.

Laboratory analysis

Particle Size Distribution using Calgon as dispersant was determined by the modified Bouyoucous hydrometer method as described by Gee and Orr (2002). Saturated hydraulic conductivity was determined by the constant-head permeameter method. Bulk density was determined by the method described by Grossman and Reinsch (2002) and calculated using the formula.

$$\rho_b = \frac{Ms(\mathrm{g})}{Vs(\mathrm{cm}^3)}$$

Where, ρ_b= Bulk density, Ms = Mass of Oven dry soil, Vs = Volume of core sampler obtained using the relation (v = $\pi r^2 h$), where r and h are taken from the core sampler. Soil total Porosity was computed from the values of bulk density and particle density as:

$$f = \left[1 - \left(\frac{\rho_b}{\rho_s}\right)\right] X\ 100$$

Where, f = porosity, ρ_b = bulk density (g/cm^3), ρ_s= Particle density (2.65 g/cm^3 for tropical soils). Gravimetric moisture content was determined by Cater, (1993) method:

$$\text{MC \%} = \frac{\text{Weight of wet soil (g)} - \text{oven dry weight (g)}}{\text{oven dry weight (g)}} \text{ X } 100$$

$$\text{FC \%} = \frac{\text{2 days Weight (g)} - \text{oven dry weight (g)}}{\text{oven dry weight (g)}} \text{ X } 100$$

$$\text{PWP \%} = \frac{\text{10 days Weight (g)} - \text{oven dry weight (g)}}{\text{oven dry weight (g)}} \text{ X } 100$$

Where; M C = Moisture Content at Saturation, F C = Field Capacity, P W P = Permanent Wilting Point

Computation of microaggregate stability indices

Dispersion ratio (DR)

Dispersion ratio was obtained by dividing the suspension percentage by the total percentage of silt and clay of the soil and multiplying by 100 (Middleton, 1980) thus:

$$\text{DR} = \frac{(\%\, silt + \%Clay\ dispersed\ in\ calgon)}{(\%\, silt + \%\, Clay\ dispersed\ in\ water)}$$

Clay dispersion ratio (CDR)

Clay dispersion ratio (CFI) was calculated from particle size distribution. The clay fraction that was obtained by chemical dispersion was taken as total clay (TC) while water dispersible clay (WDC) was obtained without chemical dispersion. CDR is computed by dividing the value of WDC by TC:

$$\text{CDR} = \frac{Water\ Dispersable\ Clay}{Total\ Clay}$$

Clay dispersion index (CDI)

Clay dispersion Index (CDI) was calculated by dividing the percentage clay obtained without chemical dispersion with percentage clay obtained by chemical dispersion (Calgon) and multiplying the result by 100:

$$\text{CDI} = \frac{\%\, clay\ dispersed\ in\ water}{\%\, clay\ dispersed\ in\ calgon}\ X\ 100$$

Modified clay ratio (MCR)

Modified clay ratio (MCR) was determined by summing up the percent of sand and percent of silt and dividing by the sum of percent of clay and percent of organic matter.

$$\text{MCR} = \frac{(\%\, silt + \%\, sand)}{(\%\, clay\ + \%\, organic\ carbon)}$$

Silt clay ratio (SCR)

Silt Clay ratio (SCR) was calculated by dividing the total percentage of silt with the total percentage of clay:

$$\text{SCR} = \frac{(\%\, silt)}{(\%\, clay)}$$

Clay flocculation index (CFI)

Clay flocculation index (CFI) was calculated by subtracting the total percentage of clay treated with water from the total percentage of clay treated with Calgon, and dividing by the total percentage of clay treated with Calgon and thereafter multiplying by 100:

$$\text{CFI} = \frac{\%\, clay\ (dispersed\ in\ calgon) - clay\ (dispersed\ in\ water)}{\%\, clay\ (dispersed\ in\ calgon)}$$

Aggregated silt clay (ASC)

Aggregate silt clay (ASC) was calculated as follows:

ASC = % Clay + Silt (Calgon) - % Clay + Silt (water)

The bulk soil samples were air-dried and sieved through a 4mm mesh and used for the following laboratory analysis. The soil samples will be further sieved through a 2 mm mesh and used for the determination of particle size distribution with water and chemical dispersion (Calgon) by the Bouyoucos hydrometer method.

Aggregate size distribution (macro and micro) and mean weight diameter

Aggregate size distribution was determined with a set of sieve sizes of 4, 2, 0.25, 0.5 and <0.05mm, corresponding to large macroaggregates, small macroaggregates, microaggregates and mineral fractions, and determined as dry and wet aggregates (described by Nimmo and Perkins, 2002).

Mean weight diameter (MWD) of dry and wet stable aggregates was determined from the equation:

$$MWD = \sum_{i=1}^{n} w_i x_i \,/ \sum w_i$$

Where, x_i = mean diameter of the ith aggregate fraction in sieve, w_i = mass of aggregates in the fraction, $\sum w_i$ = total mass of the sample.

Geometric mean diameter

This was calculated from (page 76 in RUSLE handbook) and given as:

Dg= exp[0.01*SUM (wi*Log(mi)]

Where, Dg=Geometric mean diameter, Mi= average diameter for each particle size class, Wi= corresponding mass fraction for each particle class

Water stable aggregates

The stability of aggregates to water or percent wet aggregate stability (%WSA) was determined with the 0.25mm sieve (Nimmo and Perkins, 2002), and subsequently, the percentage water stable aggregates (WSA) <0.25mm was computed as follows (Hillel, 1980).

$$\mathrm{WSAi} = \frac{Msoil,i - Msa \quad ,i}{Msoil,t - Msa \quad ,t} \times 100$$

Where, $M_{soil,i}$ = total mass of oven dry soil material after wet sieving, $M_{sand,i}$ = oven dry weight of sand in the oven dry soil mass, $M_{soil,t}$ = total mass of the whole soil sample and $M_{sand,t}$ = total mass of sand in the whole soil sample.

Statistical analysis

Data collected were analyzed using Genstat 12th Edition and mean separation was done using Fisher Least Significant Difference at 5% probability level.

RESULTS AND DISCUSSION

Effects of microbial inoculant on soil physical properties

Table 1 shows that application of microbial inoculant significantly influenced soil physical properties. In the dry season, the result of the particle size analysis using Calgon as dispersant shows that microbial inoculant application significantly ($p<0.05$) reduced Sand content from 92.50 - 93.56% when compared to control. Silt content was increased from 0.61 – 1.04 with the highest values recorded in FF4 soils, Clay content was increased from 4.90 – 6.35 with the highest values obtained in FF4 soils when compared to control respectively. Microbial inoculant application significantly ($p<0.05$) reduced Soil bulk density in FF3 soil. Soil porosity was highest (54.89%) under FF3 soils. while Soil hydraulic conductivity gave the highest value of 1.89cm/h^{-1} in FF2 soil. The low bulk densities indicated that the soils are not compacted and have more porosity (Attah, 2010). This is beneficial to root activity, water infiltration and overall growth of crops. Generally, loose, porous soils and those rich in organic matter have lower bulk density. In the wet season, the result of the particle size analysis using Calgon as dispersant shows that microbial inoculant application significantly ($p<0.05$) increased Sand content ranging from 92.80 – 93.28 with the highest values obtained in FF4 soils, Silt content was increased from 0.68 – 1.15% with the highest values obtained in FF1 soils, Clay content was increased from 5.88 – 6.31% with the highest values obtained from FF3 soil when compared to control respectively. Application of microbial inoculant significantly ($p<0.05$) reduced soil bulk density in FF3 soils. The highest porosity of 55.00% was obtained in FF2 soils, while soil hydraulic conductivity was highest 1.87cm/h^{-1} in FF2 soil as well. The frequent application of microbial inoculant leads to a decrease in soil bulk density and an increase in soil porosity, resulting in higher soil hydraulic conductivity over the two-year study period. This increased hydraulic conductivity enhances the soil's ability to facilitate water movement for plant uptake. The higher the porosity the more soil aeration and water infiltration this helps root penetration for better crop growth. High value indicates that the soil is highly permeable to transmit water; erosion could be reduced under such soil condition.

Table 2 shows the effect of microbial inoculant application on soil moisture characteristics. In dry season, application of microbial inoculant significantly ($p<0.05$) increased soil moisture content, field capacity and permanent wilting point with FF4 soil having the highest values of 21.22%, 21.89%, and 18.44% for those parameters respectively. In wet season, microbial inoculant application significantly ($p<0.05$) increased soil moisture content, field capacity and permanent wilting point with FF4 and FF2 soils relative to control. Treatment application reduced soil moisture content in FF1and FF2 soils when compared to control, this could be due to microbial breakdown of organic matter and use up of plant available water. Similar increment in soil water content, field capacity and permanent wilting point was reported by Suzuki *et al.,* (2007).

Table 3 shows the effect of microbial inoculant on micro aggregate stability. In the dry season, application of microbial inoculant significantly ($p<0.05$) influenced silt clay ratio, clay dispersion ratio, clay dispersion index and modified clay ratio. Values of 0.26, 0.32, 18.33, and 1.56 were recorded in FF2 soil for SCR and CDR and FF4 soil for CDI and MCR respectively. It has been stated that soils higher in silt clay ratio are stabilized and optimum for cultivation (Ogban, 2000). In the wet season, application of microbial inoculant significantly ($p<0.05$) influenced dispersion ratio, clay flocculation index, silt clay ratio, aggregated silt clay, clay dispersion index and modified clay ratio. FF1 soil significantly ($p<0.05$) increased SCR, ASC, CDI, and modified clay ratio with values of 0.28, 4.05, 17.04, and 1.84 respectively for the soil.

Table 1: Effects of microbial inoculant on soil Bulk density, Porosity and Hydraulic properties for the two seasons of study.

	Dry season						Wet season					
TRT	Sand	Silt	Clay	BD Mg/m^{-3}	Porosity (%)	SHC (cm/h^{-1})	Sand	Silt	Clay	BD Mg/m^{-3}	Porosity (%)	SHC (cm/h^{-1})
Control	93.56	0.75	5.64	1.24	48.56	1.48	93.01	0.82	6.17	1.34	50.11	0.91
FF1	92.85	1.00	6.15	1.21	53.11	1.60	92.98	1.15	5.88	1.32	54.22	0.92
FF2	93.16	0.61	6.27	1.29	52.11	1.89	92.80	1.13	6.07	1.23	55.00	1.87
FF3	92.88	0.95	4.90	1.19	54.89	1.74	92.93	0.76	6.31	1.19	53.00	1.55
FF4	92.50	1.04	6.35	1.29	51.44	1.51	93.28	0.68	5.88	1.27	53.33	1.59
LSD ($p<0.05$)	0.83	0.57	1.28	0.05	2.71	NS	0.72	0.63	0.65	0.04	3.20	0.13

Bd= Bulk density, SHC= Soil hydraulic conductivity, NS = non-significant, LSD = Least Significant difference, FF= Farmers Friend inoculant; Control= 0kgFF/ha, FF1= 1kgFF/ha applied once, FF2=1khFF/ha applied 2 times, FF3=1kg/ha applied 3 times, FF4=1kg/ha applied 4 times.

Table 2: Effect of microbial inoculant on soil moisture characteristics for the two seasons of study.

	Dry season			Wet season		
TRT	MC (%)	FC (%)	PWP (%)	MC (%)	FC (%)	PWP (%)
Control	18.44	16.44	14.44	23.56	19.11	18.11
FF1	20.67	18.22	16.89	21.56	19.78	18.78
FF2	20.56	18.22	17.56	21.78	21.11	19.78
FF3	22.56	17.33	16.89	23.33	19.89	19.00
FF4	23.44	18.56	18.44	24.44	21.56	19.67
LSD ($p<0.05$)	3.38	1.48	1.50	1.78	1.74	NS

MC= Moisture content, FC= Field capacity, PWP= Permanent wilting point, NS = Non-Significant
FF= Farmers Friend inoculant; Control= 0kgFF/ha, FF1= 1kgFF/ha applied once, FF2=1khFF/ha applied 2 times, FF3=1kg/ha applied 3 times, FF4=1kg/ha applied 4 times.

Table 3: Effect of microbial inoculant on micro aggregate stability indices for the two seasons of study.

	Dry season							Wet season						
TRT	DR	CFI	SCR	CDR	ASC (%)	CDI	MCR	DR	CFI	SCR	CDR	ASC (%)	CDI	MCR
Control	2.37	0.93	0.24	0.19	3.89	12.11	1.49	2.40	0.90	0.29	0.18	3.79	13.54	1.84
FF1	2.49	0.95	0.23	0.26	4.06	11.76	1.23	2.60	0.96	0.28	0.18	4.05	17.04	1.84
FF2	2.42	0.95	0.26	0.32	4.05	12.39	1.32	2.55	0.97	0.27	0.16	3.82	10.93	1.73
FF3	2.46	0.97	0.14	0.24	3.81	14.27	1.52	2.49	0.98	0.26	0.18	4.02	10.09	1.17
FF4	2.43	0.96	0.19	0.18	4.01	18.33	1.56	2.49	0.98	0.22	0.18	3.79	14.15	1.64
LSD($p<0.05$)	NS	NS	0.03	0.02	NS	0.03	0.01	0.12	0.05	0.02	NS	0.27	0.05	0.08

DR= Dispersion ratio, CFI= Clay flocculation index, SCR= Silt clay ratio, CDR= Clay dispersion ratio, ASC= Aggregate silt clay, CDI= Clay dispersion index, MCR= Modified clay ratio, NS = Non-significant, FF= Farmers Friend inoculant; Control= 0kgFF/ha, FF1= 1kgFF/ha applied once, FF2=1khFF/ha applied 2 times, FF3=1kg/ha applied 3 times, FF4=1kg/ha applied 4 times.

Table 4: Effect of treatment application on WSA, GMDW, MWDD, MWDW for the two seasons of study.

	Dry season				Wet season			
TRT	WSA	GMD	MWDD	MWDW	WSA	GMWD	MWDD	MWDW
Control	62.09	0.23	1.62	0.04	49.75	0.53	1.53	0.04
FF1	49.61	0.22	1.69	0.04	54.49	0.57	1.44	0.04
FF2	82.18	0.26	1.44	0.04	70.70	0.85	1.64	0.06
FF3	50.76	0.16	1.61	0.06	46.65	0.56	1.64	0.06
FF4	65.53	0.21	1.59	0.05	67.43	0.28	1.49	0.08
LSD ($p<0.05$)	4.63	NS	0.10	0.01	3.81	0.03	0.05	0.01

WSA= Water stable aggregate, GMDW= Geometric mean diameter weight, MWDD= Mean weight diameter dry, MWDW= Mean weight diameter wet, NS= Non-significant, FF= Farmers Friend inoculant; Control= 0kgFF/ha, FF1= 1kgFF/ha applied once, FF2=1khFF/ha applied 2 times, FF3=1kg/ha applied 3 times, FF4=1kg/ha applied 4 times.

Table 4 shows the effect of microbial inoculant on soil macro aggregate stability. In the dry season, microbial inoculant significantly ($p<0.05$) influenced macro aggregate stability. It was observed that FF2 soil significantly increased water stable aggregates and geometric mean weight diameter. Similarly, FF3 soil increased mean weight diameter dry and mean weight diameter wet. In the wet season, application of FF2 treatment increased water stable aggregates, geometric mean weight diameter and mean weight diameter dry, while FF4 soil had highest mean weight diameter wet.

Conclusion and Recommendations

Based on the research findings, it is evident that the increased application of microbial inoculant at FF4 soils has several positive effects on soil quality. These effects include improved soil moisture content, increased soil porosity, and reduced bulk density. The enhanced porosity facilitates better soil aeration and water infiltration, which in turn promotes improved root penetration for better crop growth. Additionally, the treatment leads to improved soil aggregates, which are crucial for sustainable crop production and environmental quality. Therefore, it is recommended that farmers in the area consider using microbial inoculant as it can significantly impact soil structure, quality, and the overall environment.

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